(12) UK Patent Application (19) GB (11) 2 250 848 (13) A

(43) Date of A publication 17.06.1992

(21) Application No 9020729.1

(22) Date of filing 24.09.1990

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(51) INT CL[5]
G07D 5/00

(52) UK CL (Edition K)
G4V VPG VPN VP2AX1 VP2A4
U1S S2213

(56) Documents cited
GB 2224590 A GB 1312195 A

(58) Field of search
UK CL (Edition K) G4V VPCA VPCB VPCC VPCD VPCX VPD VPEA VPEX VPF VPK VPN
INT CL[5] G07D 5/00 5/02 5/04 5/06 5/08 5/10, G07F 3/02

(54) **Coin validation**

(57) Coin validation apparatus comprises a coin chute including means for deriving from a coin passing through the chute a set of values related to one or more parameters of the coin, classification means which compares the set of values with a stored set of values predetermined to be representative of the different coin types of the coin set to which said coin belongs, said classification means including hierarchical means for employing a plurality of sets of stored values for performing plurality of assessments of the coin, each assessment employing a different set of stored values, whereby if on a first assessment, the coins appears to belong to a subset of coin types which cannot be distinguished by means of the stored values employed, one or more further assessments are employed using stored values designed to distinguish between the coin types of said subset. The parameters employed may be the sound emitted when the coin strikes an anvil (which is subjected to fast-Fourier transform) and weight and facetting data recorded when the coin rolls over a weighbridge.

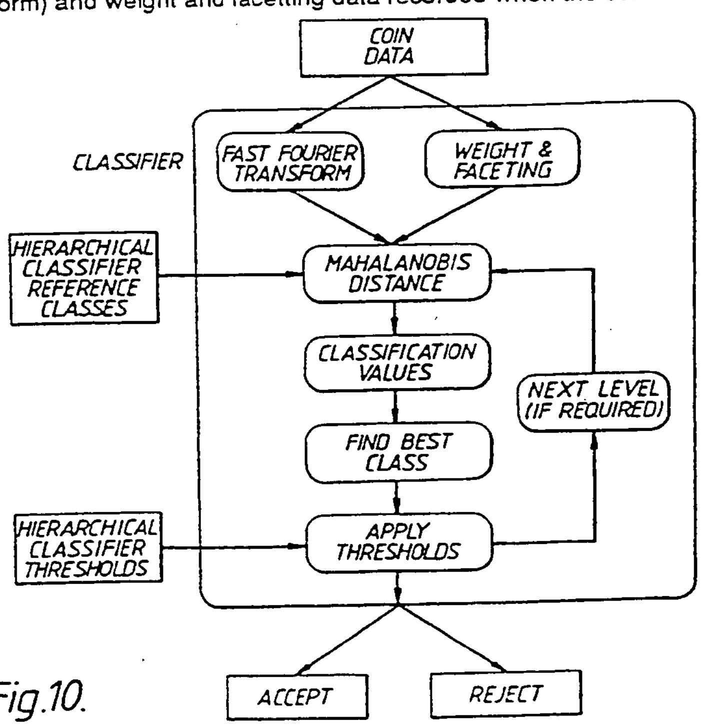


Fig.10.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

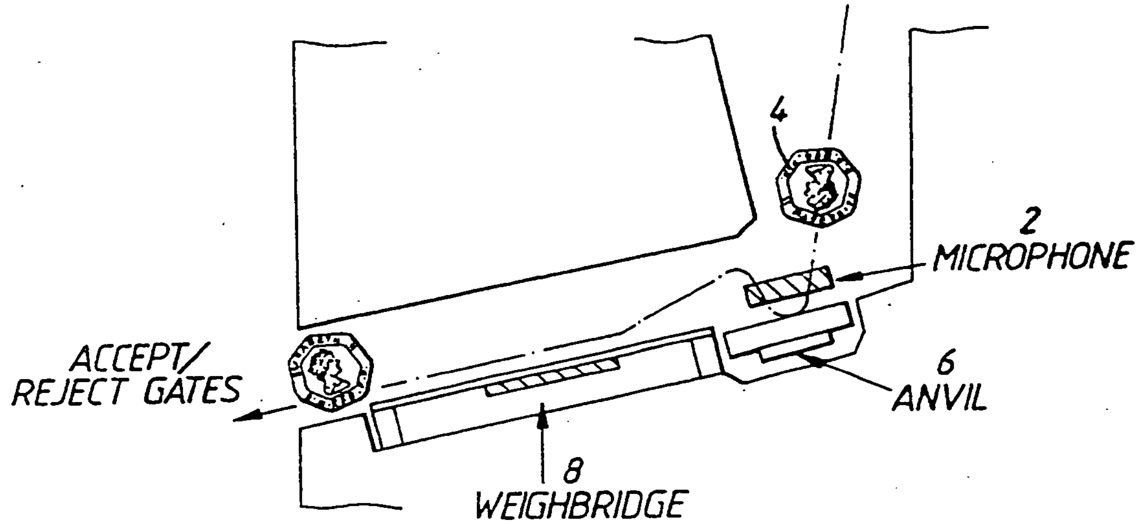

4
2
MICROPHONE
ACCEPT/
REJECT GATES
6
ANVIL
8
WEIGHBRIDGE

Fig.1.

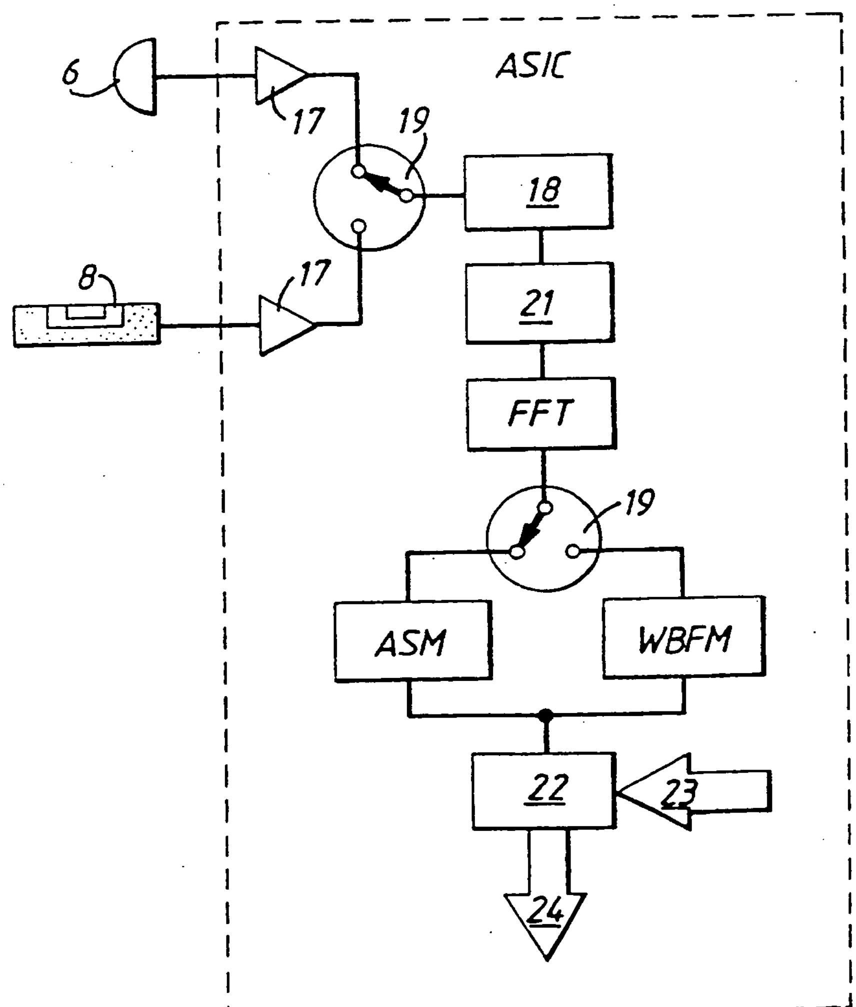

ASIC
6
17
19
18
8
17
21
FFT
19
ASM
WBFM
22
23
24

Fig.2.

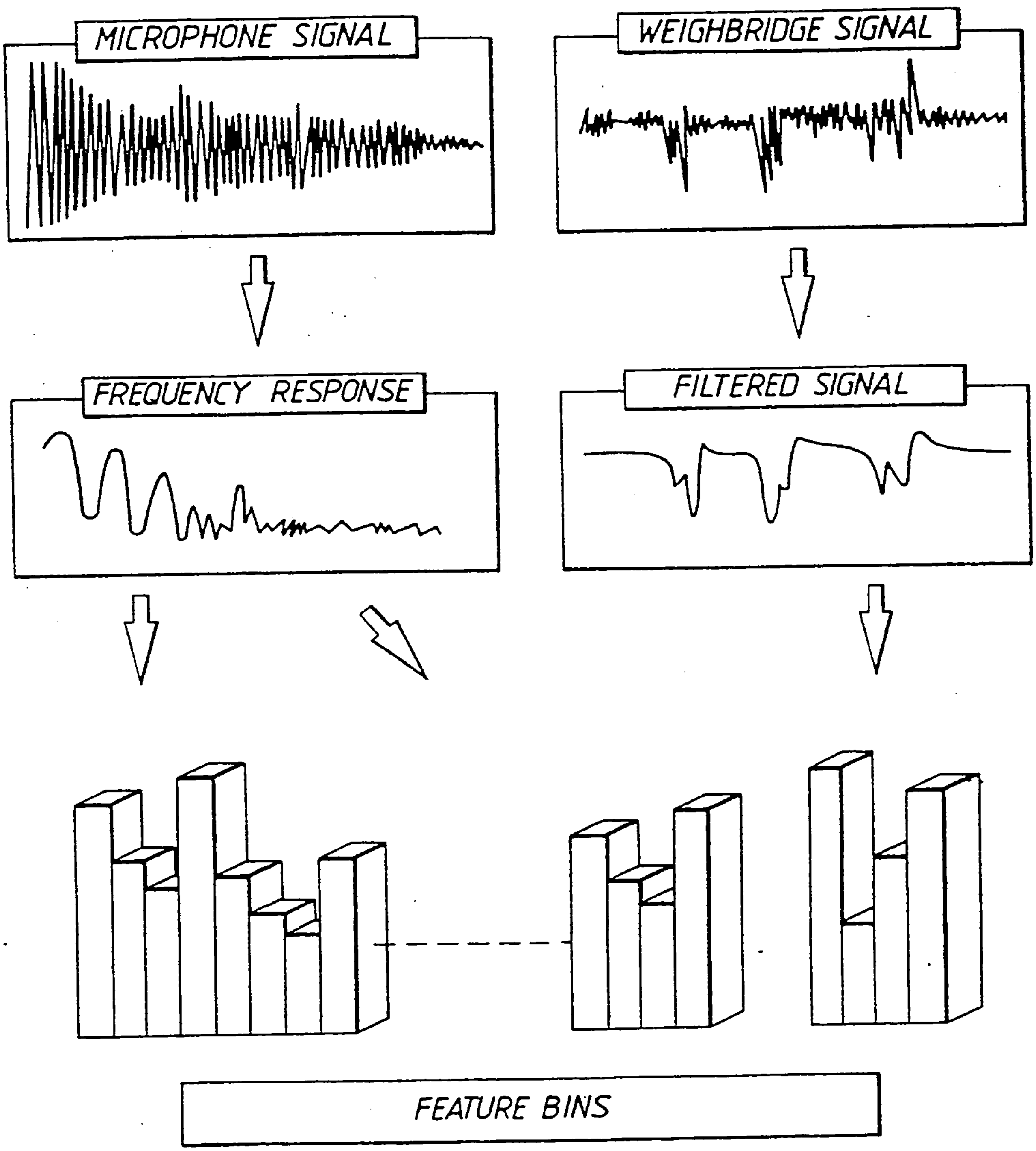
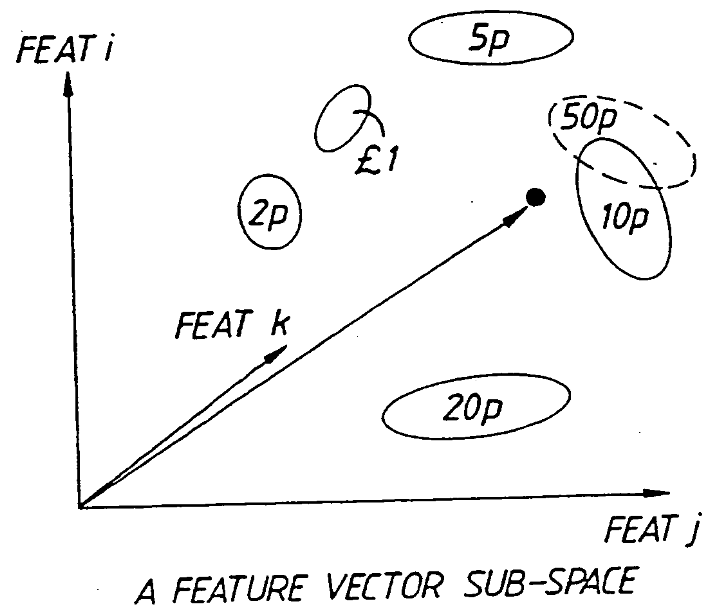

MICROPHONE SIGNAL
WEIGHBRIDGE SIGNAL
FREQUENCY RESPONSE
FILTERED SIGNAL
FEATURE BINS

Fig.3.



A FEATURE VECTOR SUB-SPACE

Fig.4.

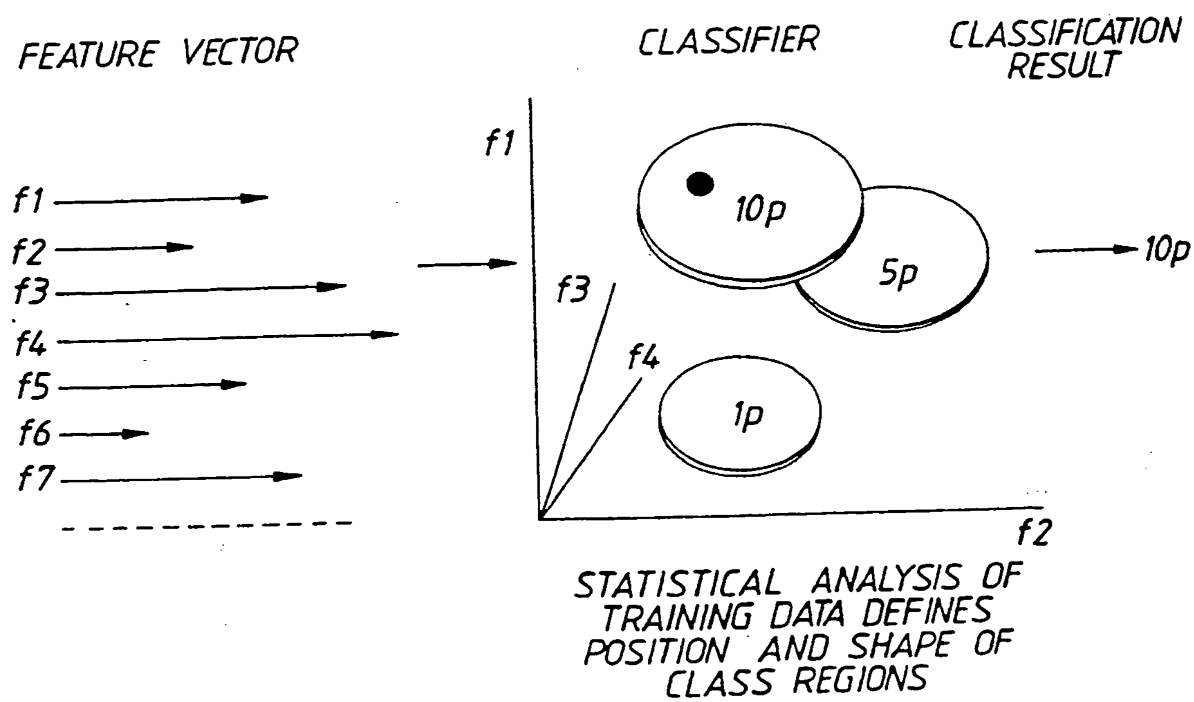


Fig.5.

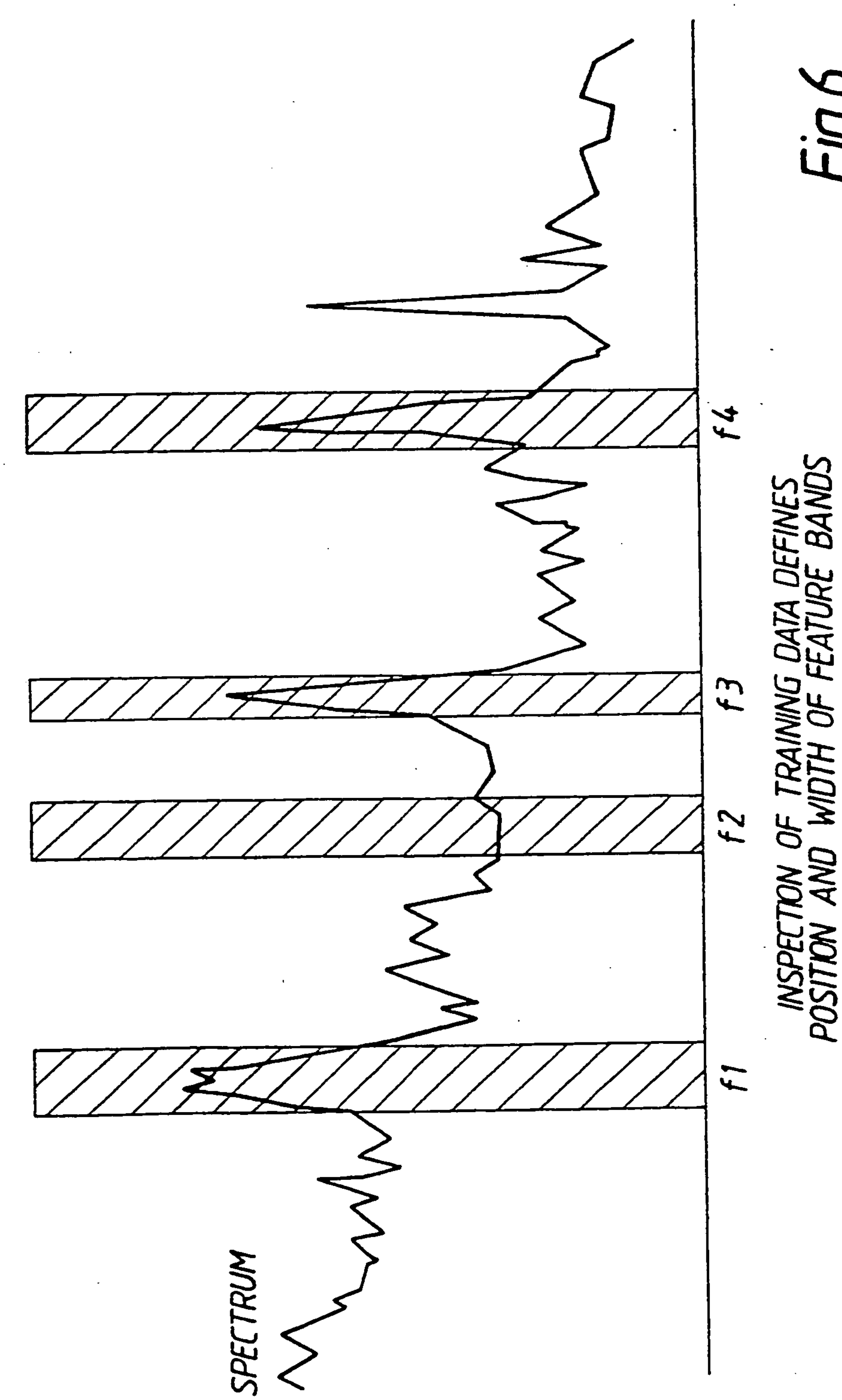

SPECTRUM
f1
f2
f3
f4
INSPECTION OF TRAINING DATA DEFINES
POSITION AND WIDTH OF FEATURE BANDS

Fig.6.

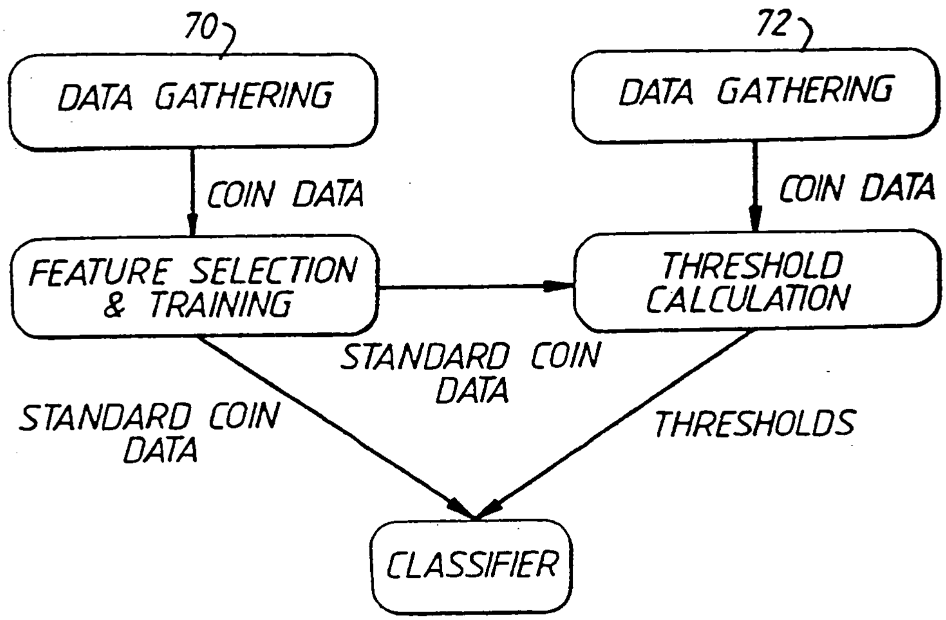

70
DATA GATHERING
COIN DATA
FEATURE SELECTION & TRAINING
72
DATA GATHERING
COIN DATA
THRESHOLD CALCULATION
STANDARD COIN DATA
STANDARD COIN DATA
THRESHOLDS
CLASSIFIER

Fig.7.

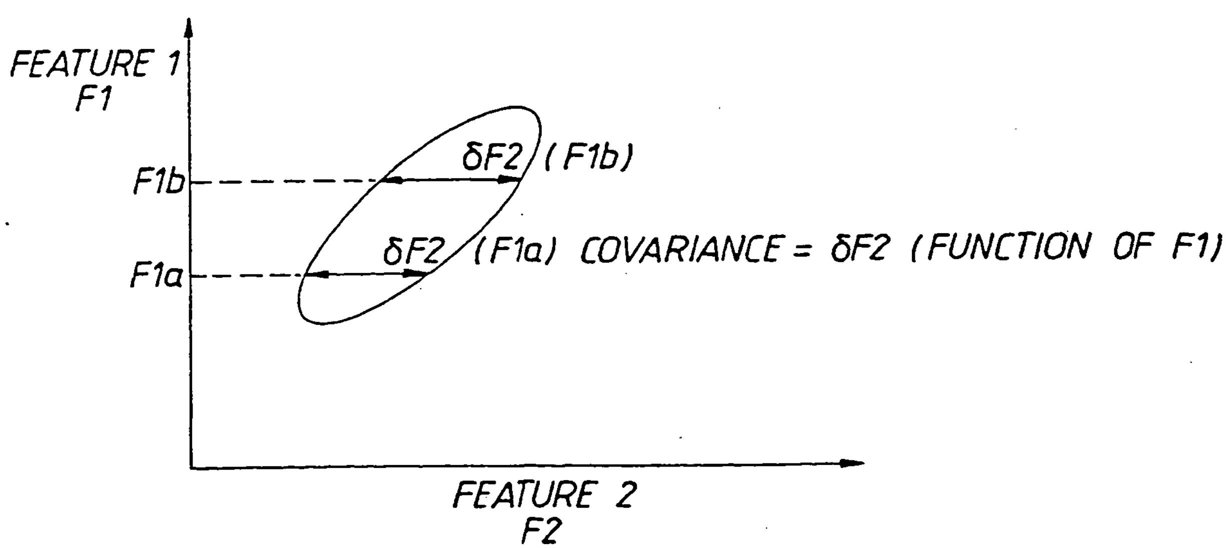

FEATURE 1
F1
F1b
F1a
δF2 (F1b)
δF2 (F1a) COVARIANCE = δF2 (FUNCTION OF F1)
FEATURE 2
F2

Fig.8B.

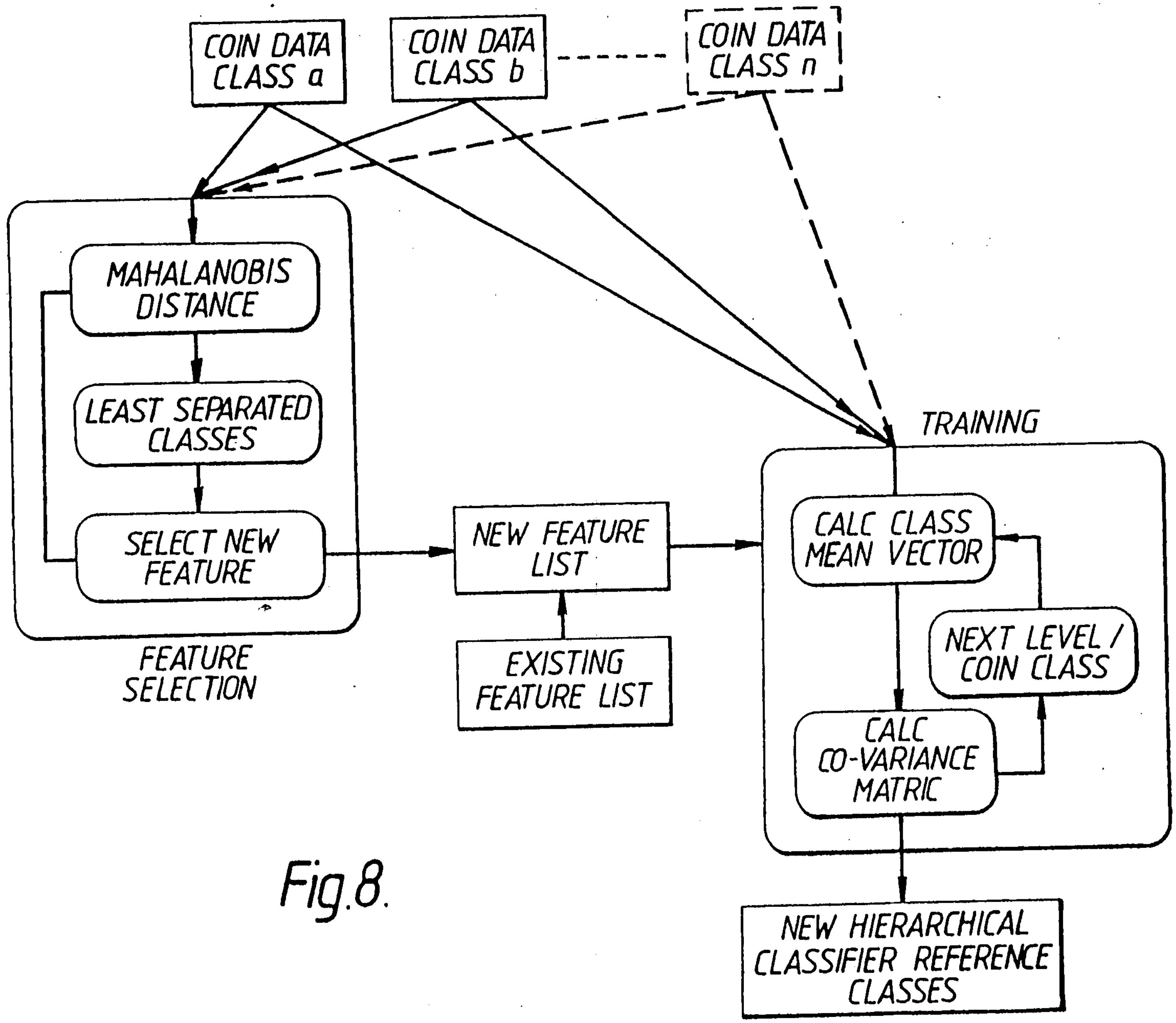

COIN DATA CLASS a
COIN DATA CLASS b
COIN DATA CLASS n
MAHALANOBIS DISTANCE
LEAST SEPARATED CLASSES
SELECT NEW FEATURE
FEATURE SELECTION
NEW FEATURE LIST
EXISTING FEATURE LIST
TRAINING
CALC CLASS MEAN VECTOR
NEXT LEVEL / COIN CLASS
CALC CO-VARIANCE MATRIC
NEW HIERARCHICAL CLASSIFIER REFERENCE CLASSES

Fig.8.

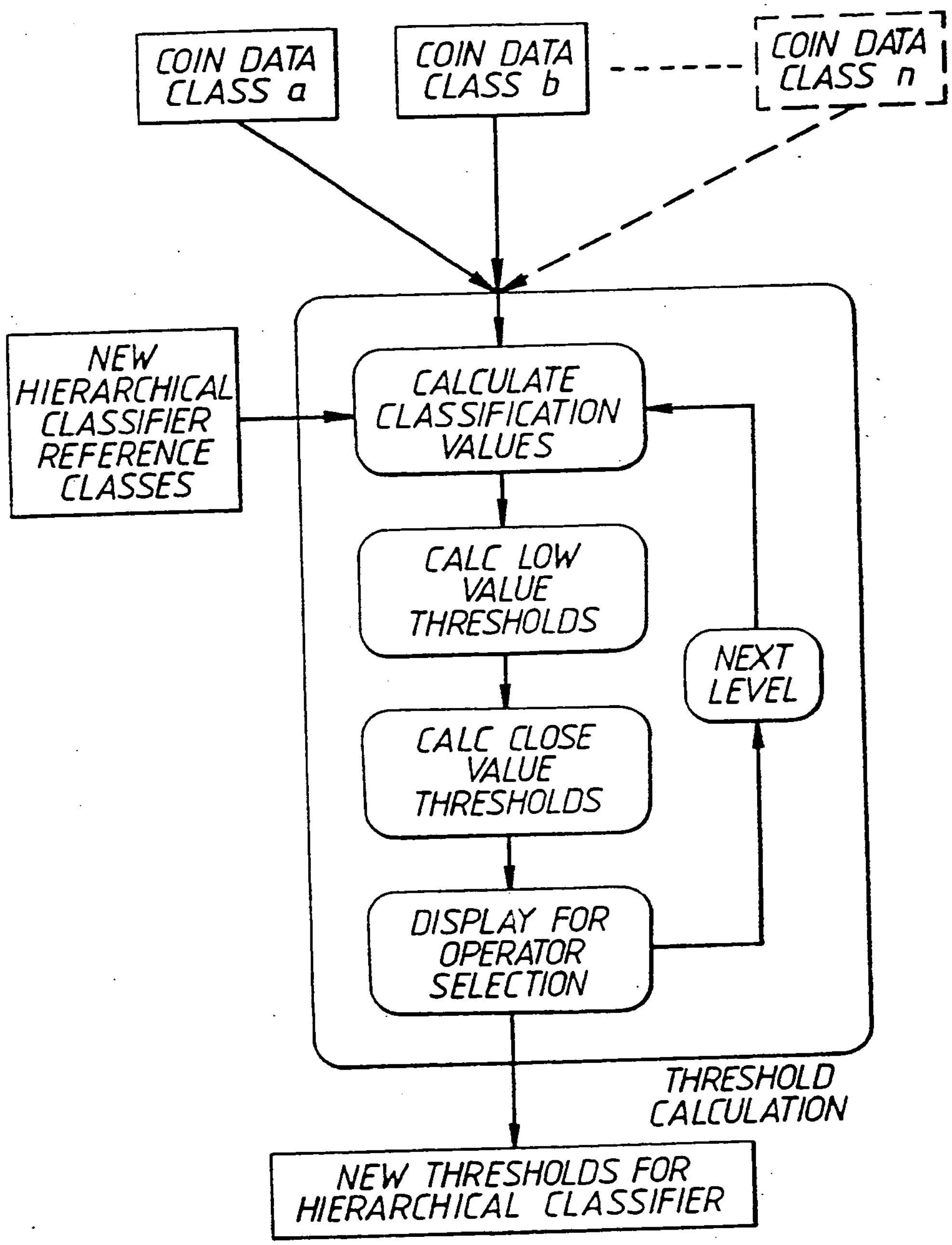

COIN DATA CLASS a
COIN DATA CLASS b
COIN DATA CLASS n
NEW HIERARCHICAL CLASSIFIER REFERENCE CLASSES
CALCULATE CLASSIFICATION VALUES
CALC LOW VALUE THRESHOLDS
CALC CLOSE VALUE THRESHOLDS
DISPLAY FOR OPERATOR SELECTION
NEXT LEVEL
THRESHOLD CALCULATION
NEW THRESHOLDS FOR HIERARCHICAL CLASSIFIER

Fig. 9A.

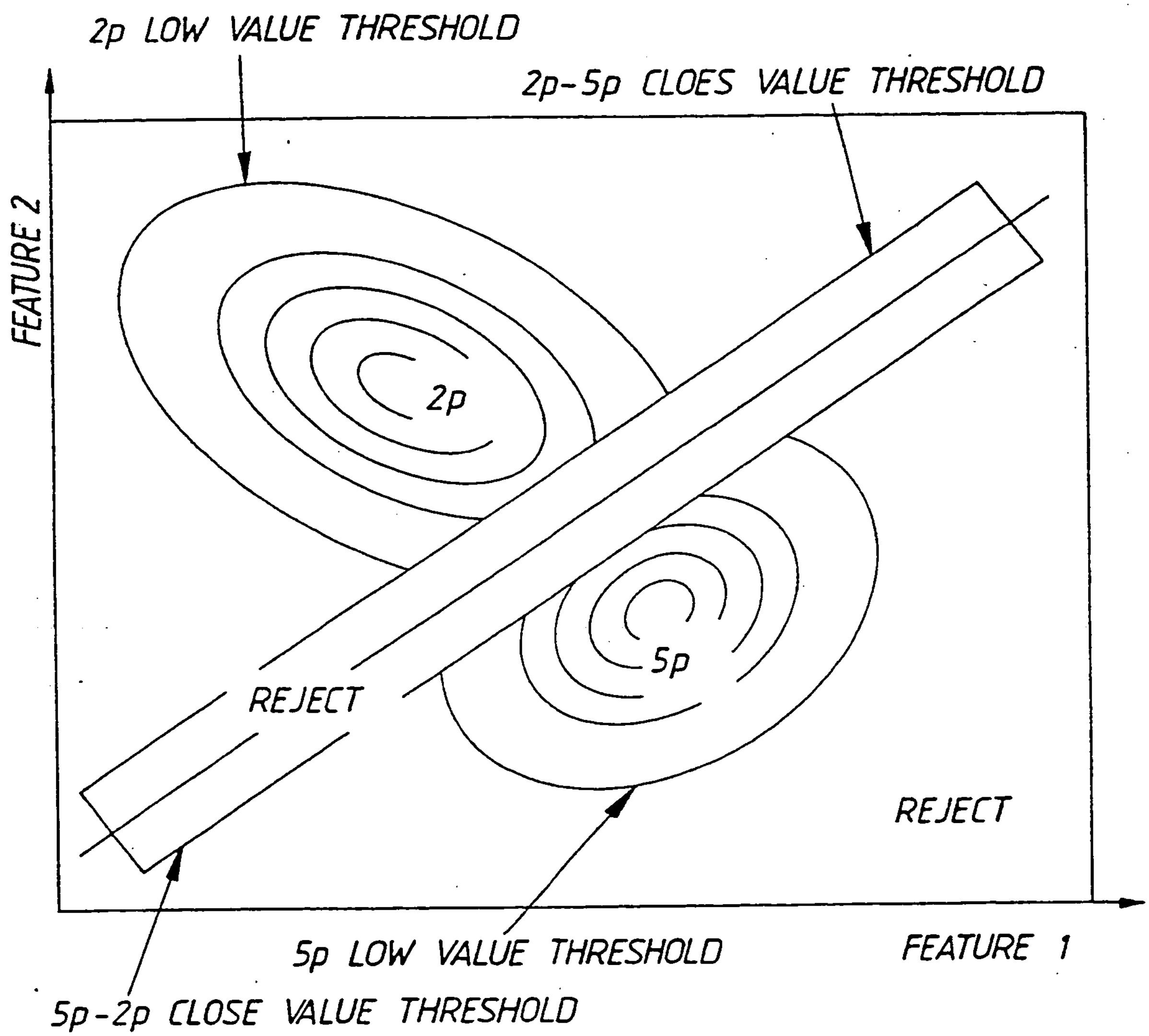

2p LOW VALUE THRESHOLD
2p-5p CLOES VALUE THRESHOLD
FEATURE 2
2p
5p
REJECT
REJECT
5p LOW VALUE THRESHOLD
FEATURE 1
5p-2p CLOSE VALUE THRESHOLD

Fig.9B.

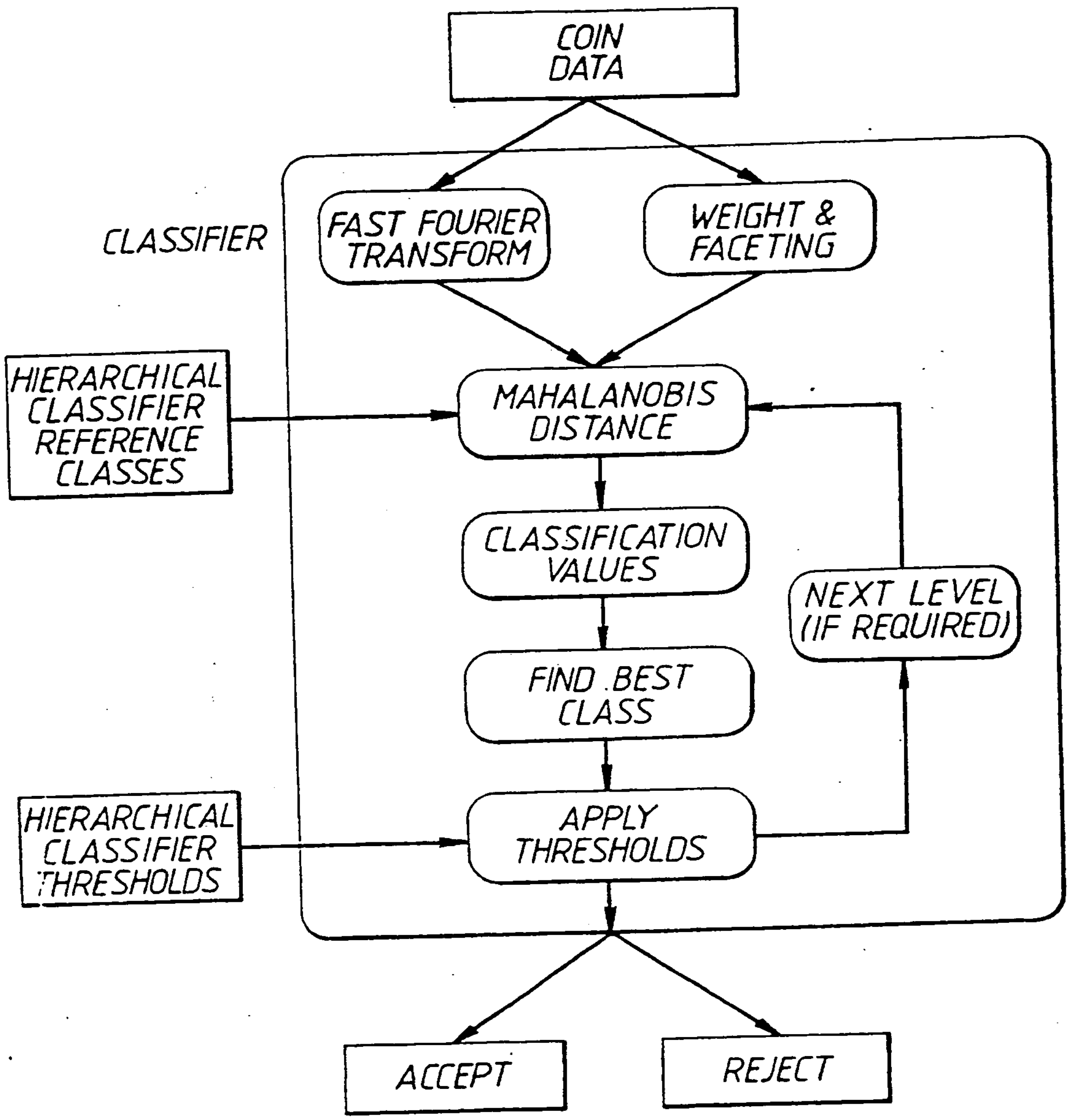

COIN DATA
CLASSIFIER
FAST FOURIER TRANSFORM
WEIGHT & FACETING
HIERARCHICAL CLASSIFIER REFERENCE CLASSES
MAHALANOBIS DISTANCE
CLASSIFICATION VALUES
NEXT LEVEL (IF REQUIRED)
FIND BEST CLASS
HIERARCHICAL CLASSIFIER THRESHOLDS
APPLY THRESHOLDS
ACCEPT
REJECT

Fig.10.

2250343

ACOUSTIC COIN VALIDATION

Field of the Invention

This invention relates to coin validation apparatus employing an acoustic means of validation, primarily intended for telecommunications applications.

Background Art

In copending application GB-A-2215505, there is disclosed and claimed coin validation apparatus comprising a coin chute arranged for directing a coin entering the apparatus such that the coin will be brought into contact with a hard striking surface, a microphone positioned to detect acoustic vibrations of the coin after striking said surface, an electronic circuit capable of comparing data from said coin with stored data representative of a set of standard coins and indicating which value of coin corresponds to that having entered said apparatus, in which the part of the apparatus before the electronic circuit includes a coin detector arranged to actuate said circuit at a time when a coin has been detected as entering the apparatus.

In copending application GB-A-2222903, there is disclosed and claimed coin validation apparatus comprising a coin chute including a hard striking surface upon which a coin entering the

apparatus is directed, a microphone positioned to detect acoustic vibrations of the coin after striking said surface, an output from said microphone being applied to signal processor means to produce a dynamic signal analysis of the coin vibrations, obtaining additional data from a weight and/or shape measuring apparatus comprising a flexible strip of resilient material which is carried on a support at each end, guide means for permitting the said coin to be rolled along the whole length of the strip thereby causing a temporary deflection of a centre portion of said strip, and a strain gauge located at the strip centre poprtion effective to produce an electrical signal representative of the deflection which is induced in the strip, comparison means for enabling the resulting vibration spectrum and electrical signal to be compared with stored data representative of a set of standard coins, and output means arranged to indicate which coin value of the expected coin set has entered the apparatus.

The coin validation arrangement of GB-A-2222903 is indicated schematically in Figure 1. It uses two coin sensors one of which is a microphone 2, listening to the characteristic sounds of a coin 4 in free flight just after bouncing on an anvil 6. The second sensor is a miniature weighbridge 8 over which the coin rolls, and which is used to increase the confidence of the validator decision by generating additional coin features, such as shape (e.g. faceted or round) and weight.

Different coins will typically have different acoustic resonant frequencies. In some cases separate coin types differ in shape but are otherwise very similar, as for example, the 10p and 50p coins in the UK set. The validator uses the output from the weighbridge sensor to help distinguish between the different coin classes in these cases. The system works by comparing the relative acoustic energies within a few key frequency bands. These frequency bands will have been selected to best differentiate between the coins ofa given set. The relative energies, together with additional weighbridge features, are used to classify the coins.

The problem then becomes that of classification of the coins to the coin types of the coin set in question. Previous methods of classification have required a large amount of manual effort to define the criteria by which the coin types are differentiated.

Summary of the Invention

It is an object of the invention to provide a means of classifying coin types of a coin set from measurements obtained employing coin validation apparatus.

The present invention is intended for use with coin validation apparatus as described in our copending application GB-A-2215505 (F20444) and GB-A-2222903 (F20572), although the present invention is applicable to any apparatus wherein acoustic vibrations of the coin are spectrally analysed.

The present invention is based on a system of classification known as statistical classification.

In order to visualise the ways in which a classifier can work, consider a simple case where to different coin features are used. A graph can be plotted, with x and y axes representing the two feature values returned by a particular coin. Coins belonging to the same class will generate features that tend to cluster around as norm. The same feature for a different coin class will tend to cluster around a different norm (otherwise this particular featur will not be useful in distinguishing between the two coin classes). In this simple two-feature example, the feature values returned by many coins will appear as N clusters on the graph, wherethereare N different coin classes. There are two main types of classifier which differ in the manner in which these clusters are segregated into the different coin classes.

A rule-based classifier will attempt to define simple boundaries between the clusters, so that all coins whose feature values fall one side of the boundary will be defined as belonging to one class. An alternative approach is that used by statistical classifiers, which attempt to model the density of the clusters in statistical terms. The cluster can be represented by a mean position, with the cluster spread defined in terms of standard deviations. Hence the difference between a particular coin feature value and the mean feature value for that class of coin can be expressed in terms of standard deviations. This normalised difference is called the Mahalanobis distance. For a particular coin of unknown class, N Mahalanobis distances can be calculated, corresponding to the N possible coin classes. The coin is then assigned to the coin class giving rise to the smallest Mahalanobis

distance.

In a first aspect of the invention , a means is provided for automating the procedure for adapting a coin validator to any given coin set.

In the case of coin validation apparatus disclosed in GB-A-2222903 (F20572), the best acoustic and weighbridge features to use are selected automatically. Having selected the appropriate frequency bands and weighbridge features, the system assigns appropriate weightings to each of these features as part of a training mode of operation. Unlike facilities available with current validators, where any change in the coin set requires considerable manual effort to re-tune the system, the system of the present invention is particularly adapted for such situations, since the system merely undergoes a further training procedure for the new coin set. In commercial use it is envisaged that the validators will be remotely reprogrammable via the telephone line, when new coins are introduced or where particular account must be taken of a new discovered fraudulent 'slugs'.

In some coin sets, it is difficult to distinguish between two valid coin classes - the existing validators have to be very finely tuned to differentiate between 10p and 50p coins reliably. In asecond aspect of the invention, the validator can detect that a particular coin has been classified as one of these uncertain classes, and instigate a second level of classifier, tuned to differentiate between the difficult classes alone. If necessary, this approach can be repeated several times for a particular coin, at each level classifying the coin data against fewer coin classes. There is no contraint on the features used by any one classifier, as each can classify on a totally different set of coin features if required.

With such hierarchical classification technique the validator attempts to classify a coin into one of several (typically 6) acceptable coin types, or rejects it. If there is known to be some possible confusion between two or more coin classes, the coin sensor data of any coin which appears to fall in these classes is examined by a second level of classifier, which attempts to distinguish between such classes only, or to reject the coin.

At worst, each such level of classifier will be able to reliably distinguish one coin class from all of the allowable coin

classes (otherwise there would be no point in having this particular level of classifier). This implies that if there are n allowable coin classes that the validator can assign the coin to, there will be a maximum of n levels of hierarchical classifier.

Brief Description of the Drawings

A preferred embodiment of the invention will now be described with reference to the accompanying drawings, wherein :-

Figure 1 is a schematic view of an acoustic coin validator as described in our copending application (F20572);

Figure 2 is a block diagram of a circuit for analysing the signals from the validator of Figure 1;

Figure 3 is a diagram illustrating the extraction of frequency information into frequency bins;

Figure 4 is a diagram showing the classification of coin types in a coin set in a feature vector sub-space;

Figure 5 is a diagram indicating the statistical analysis of data in a training mode of operation;

Figure 6 is a diagram illustrating the inspection of training data.

Figures 7 to 10 are flow charts illustrating the means of feature selection, training threshold calculation and classification according to the invention.

Description of the Preferred Embodiments

Referring now to the circuit of Figure 2, the signals produced by the microphone 6 and piezoelectric weight-bridge 8 are first amplified and then passed to the validation circuit for analysis. The sound emitted by the coin 1 is analysed in the frequency domain. In the circuit shown in Figure 2, the acoustic signal is first amplified by passage through a preamplifier 17 and then passed through a software-controlled switch to an analogue to digital convertor 18 which digitises the signal. The circuit includes two software-controlled switches 19. The digitised sample is stored in a memory 21. The time domain sample is then converted to a frequency domain spectrum using a fast-Fourier transform circuit (FFT). The strength of the signal ($S_1, S_2 \ldots. S_i$) is recorded in a

set of specified frequency bands ($f_1, f_2 \ldots f_i$), preselected on the basis of measurements on the set of coins to be tested for and the strengths of these signals are stored in an acoustic spectrum memory (ASM). These preselected bands were chosen to coincide with the peaks in the spectra due to the vibraitonal modes, as given in Table 1 for the UK coin set. The software controlling the system then redirects the input to take the signal from the weighbridge 8. This new signal is digitised by the same analogue-to-digital convertor 19 and the digitised signal stored in the memory 21. The same FFT circuit is used to recalculate the feature of the weighbridge signal to represent weight and facetting of coins and is stored in a weighbridge spectrum memory (WBSM). These features form feature vector components which are used in a Classifier. This classification is carried out by a classification algorithm 22. Input data for the classification algorithm 22 is supplied on the line 23 and there are output lines 24 to selection logic devices.

Classification algorithm 22 comprises three separate sections:

an automatic feature selection and training program;

an hierarchical minimum error rate statistical classifier; and

a program for threshold calculation for the rejection system.

Feature Selection and Training

In the feature selection and training mode, coins of a coin set are fed automatically from a hopper mechanism (not shown) into the validator of Figure 1. This enables sufficient data to be gathered to permit the operation of feature selection and training. For each coin 'bounce', 3ms of microphone signal are sampled and transformed by FFT to 256 bins. The process is indicated in Figure 3. The energy in each of these bins is a candidate feature. The weighbridge signal is smoothed and a small number of shape features extracted from the resultant curve, such as maximum deviation, sum of major deviations, widths of peaks etc. For each coin class there is a covariance matrix on the basis set of the feature vectors, which represents the probability distribution for future measurements.

For a practicable classifier, a good subset of features (two weighbridge and 10 frequency features are typically used here) must be selected. The selection of an optimum feature set of given dimension is not practicable, but a good set can be derived by choosing features, in order, which best improve the class discrimination. The metric of discrimination is taken to be the Mahalanobis distance. Where n features have already been selected there are two potential strategies for choosing the best (n+1)th feature:

In the space of (n+1) features choose the (n+1)th feature to maximise the minimum distance between classes.

In the space of n features choose the pair of classes with the minimum separation. Choose the (n+1)th feature such that the separation of this pair of classes in the space of (n+1) features is maximised - this is known as hierarchical classification.

The latter method has been implemented, because of its simplicity - at each stage of feature selection we need only look at the effect of introducing a new feature on the separation of a single pair of classes.

Hierarchical Classification

The basic classification process is simply that of finding the minimum Mahalanobis distance between the observed feature vector and the class means vectors, the actual discriminant function used being the logarithm of the multivariate normal density probability function. The greatest value of this function is the most probable class.

For some coin sets, it is difficult to distinguish between two valid coin classes. The validator must detect when a coin has been classified as belonging to an uncertain class and activate a further level of classifier, tuned to disambiguate the difficult classes. If necessary this process can be repeated several times for a particular coin, at each level classifying the coin data against fewer classes. There are no constraints on the feature sets used by different levels of classifier - they could be completely orthogonal and of different dimensionality. An hierarchical classifier is also desirable, because it can reduce the time required for

classification.

Consider an example, where there are six acceptable coin classes, namely coin types A, B, C, D, E, and F. In this hypothetical coin set, coin types A and B are easily confused, as are coin types D, E and F, with E and F particularly difficult to distinguish.

First coin, 'a'

1st level classifier attempts to classify coin as one of coin types A, B, C, D, E, F or reject.

Result of 1st level of classifier = coin type B

Coin type B is easily confused with coin type A, so further classification work is required.

2nd level classifier attempts to classify coin as one of coin types A, B or reject.

Result of 2nd level of classifier - coin type A.

Second coin, 'c'

1st level classifier attempts to classify coin as one of coin types A, B, C, D, E, F or reject.

Result of 1st level of classifier = coin type C

Coin class C was not confused with any other class, so there is no need for any further levels of classifier.

Third coin, 'd'

1st level classifier attempts to classify coin as one of coin types A, B, C, D, E, F or reject.

Result of 1st level of classifier = coin type E

Coin type E is similar to coin types D and F, so further classification work is required.

2nd level classifier attempts to classify coin as one of coin types D, E, F or reject.

Result of 2nd level of classifier = coin type D

This level of classifer can reliably segregate coin type D and coin types E and F, so no further levels of classifier are required.

Fourth coin, 'e'

1st level classifier attempts to classify coin as one of coin types A, B, C, D, E, F or reject.

Result of 1st level of classifier = coin type E

Coin type E is similar to coin types D and F, so further classification work is required.

2nd level classifier attempts to classify coin as one of coin types D, E, F or reject.

Result of 2nd level of classifier = coin type E

It is still uncertain as towhether the coin is of type E or F, so a third level of classifier is used.

3rd level classifier attempts to classify coin as one of coin types E, F or reject.

Result of 3rd level of classifier = coin type E

No further levels of classifier are required for this coin, as all ambiguity has been resolved.

The above examples show that the result from any particular level of classifier determines the relevant classifier to use for the next level. This is the key feature of a hierarchical classifier, and (to the best of our knowledge) there is no equivalent in use in existing coin validator.

Threshold Calculation for Rejection/Acceptance

Rejection is desirable where

The classification value is lower than expected

The classification value of another class is unusually close

Each class has a threshold that the classification value must exceed and thresholds that determine the minimum margin between it and the classification values for each classes. Thresholds are calculated from the values required to reject a given percentage of the members of each class, due to one or other of the above conditions. The performance figures (error and acceptance rates) are presented to the operator so that the optimum thresholds for the task may be selected. This process could be automated if necessary.

Referring now to Figures 7, 8, 9 and 10, these illustrate the means of classifying according to the invention.

Referring first to Figure 7, it may be seen there is a first data gathering operation 70 in which a number of coins of a coin set are repeatedly fed into the validator of Figure 1 in order to gather sufficient amount of coin data to enable the feature selection and training mechanism. A separate data gathering operation 72 is required to gather coin data for threshold calculation for calculation of the thresholds relating to the various features which have been selected as being discriminatory of the various coin types. The data derived from the frequency selection and threshold calculations are provided to a classifier for classifying subsequent coins entering into the coin validator.

Referring now to Figure 8, this shows in more detail the steps of feature selection and training. Data for the respective coin classes is analysised to derive the Mahalanobis for each candidate feature. As stated above the Mahalanobis distance is the number of standard deviations of the distance of a coin from the statistical mean value. The candidate features are compared and one or more features is selected which provide the greatest distinction for those classes of coins which are least separated. Such selected features are added to a feature list stored in memory.

To form a reliable means of sorting coins, it is necessary to know for each feature the mean value of the vector for each class and where a number of features have been selected to distinguish between coins of various classes, it is necessary to calculate a covariance matrix which provides an indication of the amount one feature varies where the values of the other features are held constant. In the case of an hierarchical classifier, a different set of features will normally be employed at each level of the classifier in order to reliably distinguish between the coins concerned at each level of the classifier. The training function calculates the mean vector and the covariance matrix for each level of the hierarchi.

The functions indicated in Figure 8 will provide for many types of coin an adequate means of classification. However as indicated in Figure 9B, there are situations where the coin may not be distinguishable between two classes, because the statistical variation of the two classes overlap to a greater extent, or alternatively a particular coin may have a set of values for the

features which are so far away from the calculated mean values as to make any comparison meaningless. In order to overcome these problems, as indicated in Figure 9B, threshold values are calculated in order to provide safety margins in areas of confusion so that any coin falling out of the low value threshold as indicated in Figure 9B will not be assigned to a class and any coin falling within the close value thresholds as indicated in Figure 9B will be subject to a further level of the hierarchical classifier since an adequate classification cannot be made if the coin falls within the close value threshold values. As indicated in Figure 9A the thresholds are calculated employing a new set of coin data (since otherwise the threshold values calculated may be specifically related to the data used for the features selection process). In an hierarchical classifier, it is necessary to calculate a set of threshold values for each level of the classifier. Nevertheless, this involves a greatly reduced number of calculations and would be required in a non hierarchical classifier. At each level of the classifier, low value thresholds and close value thresholds are calculated for those coin classes which it is desired to distinguish. The actual threshold values may be selected manually, or if the types of false coins or 'slugs' which may be encountered are known, the thresholds may be calculated automatically. The threshold calculation is repeated for each level of the hierarchi.

The above processes then provide a four method of classification, and the classification is shown in Figure 10 wherein a coin passed into a validator is subject to a fast-Fourier transform of the sound emitted when it strikes anvil 6 and the weight and facetting data is also recorded when the coin rolls over weightbridge 8. From these values, for each level of the hierarchical classifier, the Mahalanobis distance is calculated for the features of interest. This is compared with the classification values for the various coin types and the best class for the coin is located. For that level of the hierarchical classifier, the thresholds are applied to ascertain whether the coin can be accepted or rejected at that level of classification. If the coin falls within a close value threshold then the classifier goes to the next level of classification and the classification steps are repeated until sufficient levels of the hierarchical classifier are processed in order to unambiguously defy.

CLAIMS

1. Coin validation apparatus comprising a coin chute including means for deriving from a coin passing through the chute a set of values related to one or more parameters of the coin,

classification means which comprises the set of values with a stored set of values predetermined to be representative of the different coin types of the coin set to which said coin belongs,

said classification means including hierarchical means for employing a plurality of sets of stored values for performing plurality of assessments of the coin, each assessment employing a different set of stored values,

whereby if on a first assessment, the coin appears to belong to a subset of coin types which cannot be distinguished by means of the stored values employed, one or more further assessments are employed using stored values designed to distinguish between the coin types of said subset.

2. Apparatus as claimed in Claim 1 including anvil means against which a coin strikes in movement through the chute, a microphone for detecting vibrations of the coin resulting from the striking of the anvil, and transform means for transforming the detected vibrations into a set of frequency values.

3. Coin validation apparatus as claimed in Claim 2 including weighbridge means is said coin chute which determines further features related to the weight of a coin on the weighbridge, and means for applying such values to the classification means for use in determining the coin type of said coin.

4. Apparatus as claimed in Claim 1, wherein the classifier is a statistical classifier.

5. Apparatus as claimed in Claim 4 wherein threshold values are provided associated with the stored values and means for determining whether a coin falls within the thresholds for reliable determination of the coin type, a different set of threshold values being provided for each set of stored values.

6. Coin validation apparatus as claimed in Claim 1 and substantially as described with reference to the accompanying

drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

9020729.1

Relevant Technical fields

(i) UK Cl (Edition K) G4V (VPCA, VPCB, VPCC, VPCD, VPCX, VPD, VPEA, VPEX, VPF, VPK, VPN)

(ii) Int Cl (Edition 5) G07D 5/00, 5/02, 5/04, 5/06, 5/08, 5/10; G07F 3/02

Search Examiner

S R SMITH

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

20 DECEMBER 1991

Documents considered relevant following a search in respect of claims 1-6

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2224590 A (PLESSEY) see especially lins 4 to 20 of page 2, last line of page 5 to line 8 of page 6, lines 11 to 19 of page 9	1,2,3, 4,5
X	GB 1312195 (MARS) see lines 104 to 115 of page 3, last line of page 3 to line 24 of page 4	1

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

Published 1992 at The Patent Office, Concept House, Cardiff Road, Newport, Gwent NP9 1RH. Further copies may be obtained from Sales Branch, Unit 6, Nine Mile Point, Cwmfelinfach, Cross Keys, Newport, NP1 7HZ. Printed by Multiplex techniques ltd, St Mary Cray, Kent.